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Upland Rice Genotypes Evaluation for Phosphorus Use Efficiency

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ABSTRACT

Phosphorus (P) deficiency is one of the most important yield-limiting factors in acid soils in various parts of the world. The objective of this study was to evaluate the growth and P-use efficiency of 20 upland rice (*Oryza sativa* L.) genotypes at low (0 mg P kg^{-1}), medium (75 mg P kg^{-1}), and high (150 mg P kg^{-1}) levels of applied P on an Oxisol. Plant height, tillers, shoot and root dry weight, shoot-root ratio, P concentration in root and shoot, P uptake in root and shoot, and P-use efficiency were significantly ($P<0.01$) affected by level of soil P as well as genotype. Shoot weight and P uptake in shoot were found to be the plant parameters most sensitive to P deficiency, suggesting that these two parameters may be most suitable for screening rice genotypes for P-use efficiency under greenhouse conditions.

INTRODUCTION

Phosphorus deficiency has been identified as one of the major limiting factors for crop production in highly weathered soils (such as Oxisols and Ultisols) in many parts of the world (Haynes, 1984; Sanchez and Salinas, 1981). In addition to the natural low level of P of these soils, high P-fixation capacity makes P unavailable to plants. Several soil properties, especially clay, and iron (Fe) and aluminum (Al) contents are closely related to the P-sorption capacity of these soils.

The heterogeneity and complexity of soils make difficult the identification and study of genetically superior genotypes under field conditions. These difficulties can be reduced, to some extent, under greenhouse conditions. Plant germplasm can be grown in a homogenous medium likely to allow effective expression of mechanisms conferring adaptive value in soil (Coltman et al., 1985).

Upland rice refers to rice grown on both flat and sloping fields that are prepared and seeded under dryland conditions and depend on rainfall for moisture (Fageria et al., 1991). It is mostly grown in South America, Africa, and many parts of Asia. Among essential plant nutrients, P deficiency is identified as the most yield limiting for this crop on Oxisol soils in Brazil (Fageria, 1994). The use of efficient germplasm in combination with other management practices may be an appropriate solution to produce a rice crop on P-deficient acid soils. The objective of this study was to evaluate upland rice genotypes for their P-use efficiency.

MATERIALS AND METHODS

A greenhouse experiment was conducted to evaluate the response of 20 upland rice genotypes to low (0 mg P kg^{-1}), medium (75 mg P kg^{-1}), and high (150 mg P kg^{-1}) levels of applied P. The soil used in the experiment was an Oxisol (clayey, kaolinite, isothermic, Typic Haplustox) having the following chemical and physical properties before the application of P treatments: pH=4.9 (1:2.5 soil-water ratio), extractable P=0.4 $mg{\cdot}kg^{-1}$, extractable potassium (K)=17 $mg{\cdot}kg^{-1}$, extractable calcium (Ca)=0.3 $cmol_c{\cdot}kg^{-1}$, extractable magnesium (Mg)=0.4 $cmol_c{\cdot}kg^{-1}$, extractable Al=0.7 $cmol_c{\cdot}kg^{-1}$, extractable copper (Cu)=1.2 $mg{\cdot}kg^{-1}$, extractable zinc (Zn)=0.3 $mg{\cdot}kg^{-1}$, extractable Fe=45 $mg{\cdot}kg^{-1}$, and extractable manganese (Mn)=6 $mg{\cdot}kg^{-1}$. The organic matter content was 12 $g{\cdot}kg^{-1}$, clay content=590 $g{\cdot}kg^{-1}$, silt content=110 $g{\cdot}kg^{-1}$, and sand content=300 $g{\cdot}kg^{-1}$ of soil. Phosphorus and K were extracted by the Mehlich 1 extracting solution [0.05M hydrochloric acid (HCl)+0.0125M sulfuric acid (H_2SO_4)]. Phosphorus was determined colorimetrically and K by flame photometry. Calcium, Mg, and Al were extracted with 1M potassium chloride (KCl). Aluminum was determined by titration with sodium hydroxide (NaOH), and Ca and Mg by titration with EDTA. Micronutrients were determined on a portion of the extract of P by atomic absorption spectrophotometry. Organic matter was determined by the Walkley-Black method, and soil texture by the pipette method. Soil analysis methods used in this study are described in a soil analysis manual published by EMBRAPA (1979).

Low, medium, and high levels of soil P were established by adding triple superphosphate. The experiment was conducted with 5 kg soil contained in a plastic pot. The basal application of fertilizers in each pot was 400 mg nitrogen

(N) as ammonium sulfate [$(NH_4)_2SO_4$], 797 mg of K as KCl, 500 mg FTE BR-12 (fritted glass material that provides micronutrients), and 3 g dolomitic limestone. These basal fertilizer rates were based on the recommendations of Fageria et al. (1995).

A factorial arrangement was used with 3 P x 20 genotypes in a randomized complete design with treatments replicated three times. Each pot contained five plants. All pots were watered to maintain soil moisture at approximately field capacity throughout the growing season. Plants were harvested four weeks after sowing. After harvesting the tops, the roots were removed from each pot with use of a water jet. Roots and shoots were washed several times with distilled water. Plant material was dried to constant weight in a forced-draft oven at about 75°C and then milled. Ground plant material was digested with 2:1 mixture of nitric (HNO_3) and perchloric ($HClO_4$) acids and colorimetrically analyzed for P (Morais and Rabelo, 1986). All the data were analyzed by analysis of variance and Tukey's test was used to separate treatment means.

RESULTS AND DISCUSSION

Plant growth, P plant concentration (P content per unit dry weight), and P uptake (P concentration x dry weight) parameters were significantly ($P<0.01$) affected by P levels and genotypes (Table 1), except that root lengths for P levels and P concentration in the roots for the genotypes were not statistically significant. Two-

TABLE 1. Significance of F values and orthogonal contrasts derived from analysis of variance for variables measured on 20 upland rice genotypes planted with three levels of P.

Variable	P levels	Genotypes	P x G	P Linear	P Quadratic
Tillers	**	**	*	**	**
Plant height	**	**	**	**	**
Root length	NS	**	NS	NS	NS
Shoot dry weight	**	**	NS	**	**
Root dry weight	**	**	NS	**	**
Shoot-root ratio	**	**	*	**	**
P conc. shoot	**	**	NS	**	**
P conc. root	**	NS	NS	**	**
P uptake shoot	**	**	NS	**	**
P uptake root	**	**	NS	**	**
P-use efficiency	**	**	NS	--	--

*,**,NS=Significant at the 5% and 1% probability levels, and not significant, respectively.

way interactions (P x genotypes), however, were only significant for tillers, plant height, and shoot-root ratio. This means that the relative response of different genotypes to P level was not similar across three P levels in relation to tillers, plant height, and shoot-root ratio. All the plant parameters evaluated showed highly significant ($P<0.01$) linear as well as quadratic responses in relation to P levels. This indicates that the soil used in this experiment was highly P deficient and appropriate for the P screening study.

Plant height, shoot-root ratio, P concentration in root and shoot, and P uptake in shoot were significantly increased with increasing P levels in the soil (Table 2). Tillers, dry root and shoot weight, and P uptake in root increased significantly up to the medium P level, and when P was further increased in the growth medium, there was no statistically significant increase. Root length did not change with increasing P levels, and P-use efficiency was significantly reduced at the high P level as compared to a medium P level.

At the medium P level, the increase in plant height was 81%, for tillers 220%, dry root weight 103%, dry shoot weight 614%, shoot-root ratio 255%, P concentration in the shoot 567%, P concentration in the root 267%, P uptake in

TABLE 2. Influence of P levels on growth parameters, plant tissue P concentration, and P uptake of 20 upland rice genotypes.

Plant parameter[1]	Low P (0 mg kg^{-1})	Medium P (75 mg kg^{-1})	High P (150 mg kg^{-1})
Plant height (cm)	36c	65b	68a
Root length (cm)	40a	40a	41a
Tillers per pot	5b	16a	15a
Dry root weight (g/pot)	0.36b	0.73a	0.69a
Dry shoot weight (g/pot)	0.35b	2.50a	2.60a
Shoot-root ratio	0.97c	3.44b	3.86a
P conc. in shoot (g kg^{-1})	0.6c	4.0b	4.3a
P conc. in root (g kg^{-1})	0.6c	2.2b	2.5a
P uptake in shoot (mg/pot)	0.20c	10.06b	11.44a
P uptake in root (mg/pot)	0.19b	1.64a	1.73a
P-use efficiency (mg/mg)	--	224a	206b

[1]Data are averaged over genotypes.

Values for each plant parameter under different P levels followed by same letter are not significantly different at the 5% probability level by Tukey's test.

TABLE 3. Number of tillers and plant height of 20 upland rice genotypes under three P levels.

Genotype	Tillers/pot			Average	Plant height (cm)			Average
	Low P	Medium P	High P		Low P	Medium P	High P	
CNA 6187	5	15.0	14.0	11.3ab	33.0cde	65.7ab	68.3bcd	55.7defgh
CNA 6710	5	14.7	15.7	11.8ab	32.7cde	61.0ab	66.3cde	55.3efghi
CNA 7127	5	16.7	16.7	12.8a	32.0de	54.0b	58.3e	48.1j
CNA 7119	5	15.3	16.0	12.1ab	32.7cde	59.7ab	66.3cde	52.9ghij
CNA 7645	5	16.3	17.7	13.0a	30.0e	56.3b	61.7de	49.3ij
CNA 7680	5	14.3	14.7	11.3ab	39.3abcde	71.0ab	75.3ab	61.9abc
CNA 7681	5	14.3	14.0	11.1ab	41.3abcd	77.0a	79.3a	65.9a
CNA 7451	5	14.3	15.0	11.4ab	33.7cde	67.7ab	71.0bc	57.5cdefg
CNA 7890	5	15.0	14.0	11.3ab	41.7abc	67.7ab	70.7bc	60.0bcd
IAC 1335	5	15.7	17.3	12.7a	32.0de	61.0ab	62.0de	51.7hij
IAC 1343	5	15.3	17.3	12.5ab	32.7cde	61.0ab	61.0de	51.6hij
IAC 1205	5	15.3	15.3	11.9ab	30.7e	59.0b	61.3de	50.3ij
CNA 6724-1	5	15.0	14.0	11.3ab	34.7bcde	68.0ab	71.3abc	58.0cde
CNA 7911	5	16.3	15.3	12.2ab	37.7bcde	66.7ab	69.0bcd	57.8cdef
CNA 7864	5	18.3	15.7	13.0a	40.3abcd	70.0ab	72.7abc	61.0bc
CNA 7875	5	15.0	13.7	11.2ab	43.7ab	67.0ab	67.7bcd	59.5cd
CNA 7706	5	16.3	15.7	12.3ab	33.0cde	61.3ab	64.7cde	53.0fghi
CNA 7690	5	14.3	12.3	10.5b	47.7a	71.7ab	75.0ab	64.8ab
Rio Paranaiba	5	16.7	15.3	12.3ab	39.0abcde	66.3ab	68.0bcd	57.8cdef
Guarani	5	16.0	14.7	11.9ab	34.7bcde	69.3ab	72.0abc	58.7cd
F-test	NS	NS	NS	**	**	**	**	**
CV %		9	12	10	10	9	4	5

*,**,NS=Significant at the 5% and 1% probability levels, and not significant, respectively.
Values followed by same letters in the column are not significantly different at the 5% probability level by Tukey's test.

the shoot 4,930%, and P uptake in the root 763% as compared to the low P level. This means that, among growth parameters, dry weight of shoot was most sensitive to P deficiency, followed by shoot-root ratio and tillers. Among P uptake parameters, P uptake in the shoot showed the highest sensitivity to P deficiency, followed by P uptake in the roots. This suggests that in P-screening experiments, shoot dry weight and P uptake in the shoot are the appropriate parameters for upland rice genotype evaluation under greenhouse conditions. These results are similar to our previous study with upland rice genotypes (Fageria et al., 1988).

Phosphorus x genotype interactions were statistically significant for tillers, plant height, and shoot-root ratio (Tables 3 and 4). This means that responses of

TABLE 4. Shoot-root ratio of 20 upland rice genotypes under three P levels and P concentrations in shoot across three P levels.

Genotype	Shoot-root ratio				P conc. in shoot
	Low P	Medium P	High P	Average	(g kg^{-1})
CNA 6187	0.93	3.06ab	4.27ab	2.75abcd	3.07abc
CNA 6710	1.17	3.85ab	4.41ab	3.14a	2.80cd
CNA 7127	0.81	3.45ab	4.07ab	2.78abcd	2.90abcd
CNA 7119	0.99	3.47ab	4.06ab	2.84abc	2.77cd
CNA 7645	0.86	3.66ab	4.29ab	2.94abc	3.26a
CNA 7680	1.05	3.56ab	3.89ab	2.83abcd	3.04abc
CÁ 7681	1.12	3.65ab	4.53a	3.10ab	3.02abcd
CNA 7451	0.94	3.39ab	3.88ab	2.74abcd	2.84bcd
CNA 7890	0.93	2.47b	3.22b	2.21d	3.02abcd
IAC 1335	0.91	3.39ab	3.68ab	2.66abcd	3.02abcd
IAC 1343	0.95	3.38ab	3.70ab	2.68abcd	3.02abcd
IAC 1205	0.82	3.47ab	3.68ab	2.65abcd	2.91abcd
CNA 6724-1	1.03	3.68ab	4.26ab	2.98abc	3.28a
CNA 7911	1.06	3.75ab	4.34ab	3.05ab	2.95abcd
CA 7864	0.99	4.00a	3.98ab	2.99abc	2.92abcd
CNA 7875	0.80	2.84ab	3.60ab	2.41cd	3.06abc
CNA 7706	0.94	3.13ab	3.39ab	2.48bcd	2.74cd
CNA 7690	0.87	3.34ab	3.21b	2.47bcd	3.22ab
Rio Paranaiba	1.05	3.98a	3.54ab	2.85abc	2.90abcd
Guarani	1.16	3.39ab	3.23b	2.59abcd	2.61d
F-test	NS	*	**	*	**
CV %	16	14	11	13	8

*,**,NS=Significant at the 5% and 1% probability levels, and not significant, respectively.

Values followed by same letters in the column are not significantly different at the 5% probability level by Tukey's test.

genotypes measured in relation to these parameters were not similar across all three levels.

When P was not added in the soil (low P), rice genotypes did not produce any tillers. Tillers at the medium and high P levels were about three-fold higher as compared to the low P level. Plant height varied from 30 to 48 cm at the low P level, 54 to 77 cm at the medium P level, and 65 to 79 cm at the high P level.

TABLE 5. Root length, root dry weight, and shoot dry weight across three P levels of 20 upland rice genotypes.

Genotype	Root length (cm)	Root dry weight (g/pot)	Shoot dry weight (g/pot)
CNA 6187	41ab	0.58ab	1.73abc
CNA 6710	40ab	0.48b	1.64bc
CNA 7127	41ab	0.53ab	1.59bc
CNA 7119	40ab	0.61ab	1.89abc
CNA 7645	37b	0.51ab	1.62bc
CNA 7680	45a	0.66ab	2.14ab
CNA 7681	42ab	0.63ab	2.22a
CNA 7451	38ab	0.64ab	1.87abc
CNA 7890	41ab	0.64ab	1.52c
IAC 1335	41ab	0.55ab	1.64bc
IAC 1343	38ab	0.54ab	1.67abc
IAC 1205	36b	0.57ab	1.74abc
CNA 6724-1	41ab	0.53ab	1.80abc
CNA 7911	39ab	0.55ab	1.86abc
CNA 7864	42ab	0.64ab	2.12ab
CNA 7875	40ab	0.68a	1.75abc
CNA 7706	39ab	0.62ab	1.74abc
CNA 7690	46a	0.65ab	1.72abc
Rio Paranaiba	40ab	0.62ab	2.02abc
Guarani	38ab	0.68a	2.02abc
F-test	**	**	**
CV %	11	18	18

**Significant at the 1% probability level.

Values followed by the same letters in the column are not significantly different at the 5% probability level by Tukey's test.

These results indicate that tillers did not chage much at low and high P levels. The number of tillers is a important yield-contributing component because the number of panicles is closely associated with the number of tillers in a rice crop; and in general, increased panicles per unit area is the single most important component of yield associated with rice yield (Gravois and McNew, 1993).

TABLE 6. Phosphorus concentration in root, P uptake in root and shoot, and P-use efficiency in the whole plant (roots and shoots) of 20 upland rice genotypes across three P levels.

Genotype	P conc. in root ($g\ kg^{-1}$)	P uptake in root (mg/pot)	P uptake in shoot (mg/pot)	P-use efficiency[1] (mg dry matter/mg P absorbed)
1. CNA 6187	1.70	7.24abc	1.09ab	205ab
2. CNA 6710	1.71	6.46bc	0.93b	231a
3. CNA 7127	1.78	6.20c	1.05ab	228ab
4. CNA 7119	1.72	7.24abc	1.21ab	236a
5. CNA 7645	1.70	7.14abc	0.94b	193ab
6. CNA 7680	1.85	8.68ab	1.38a	208ab
7. CNA 7681	1.80	8.91a	1.28ab	214ab
8. CNA 7451	1.68	7.19abc	1.18ab	215ab
9. CNA 7890	1.72	6.04c	1.22ab	206ab
10. IAC 1335	1.87	6.61abc	1.18ab	220ab
11. IAC 1343	1.75	6.75abc	1.08ab	216ab
12. IAC 1205	1.74	6.81abc	1.14ab	231ab
13. CNA 6724-1	1.77	8.00abc	1.08ab	199ab
14. CNA 7911	2.05	7.35abc	1.22ab	210ab
15. CNA 7864	1.91	8.23abc	1.33ab	216ab
16. CNA 7875	1.83	7.04abc	1.34ab	213ab
17. CNA 7706	1.65	6.36bc	1.16ab	238a
18. CNA 7690	1.88	7.20abc	1.32ab	197b
19. Rio Paranaiba	1.72	7.73abc	1.20ab	231ab
20. Guarani	1.71	7.31abc	1.33ab	240a
F-test	NS	**	**	**
CV %	15	20	21	10

[1]P-use efficiency = (dry matter yield of roots and tops at medium or high P level/P accumulation in the roots and tops at medium or high P level) - (dry matter yield of roots and tops at low P level/P accumulation in the roots and tops at low P level).

*,**,NS=Significant at the 5% and 1% probability levels, and not significant, respectively.

Values followed by the same letters in the column are not significantly different at the 5% probability level by Tukey's test.

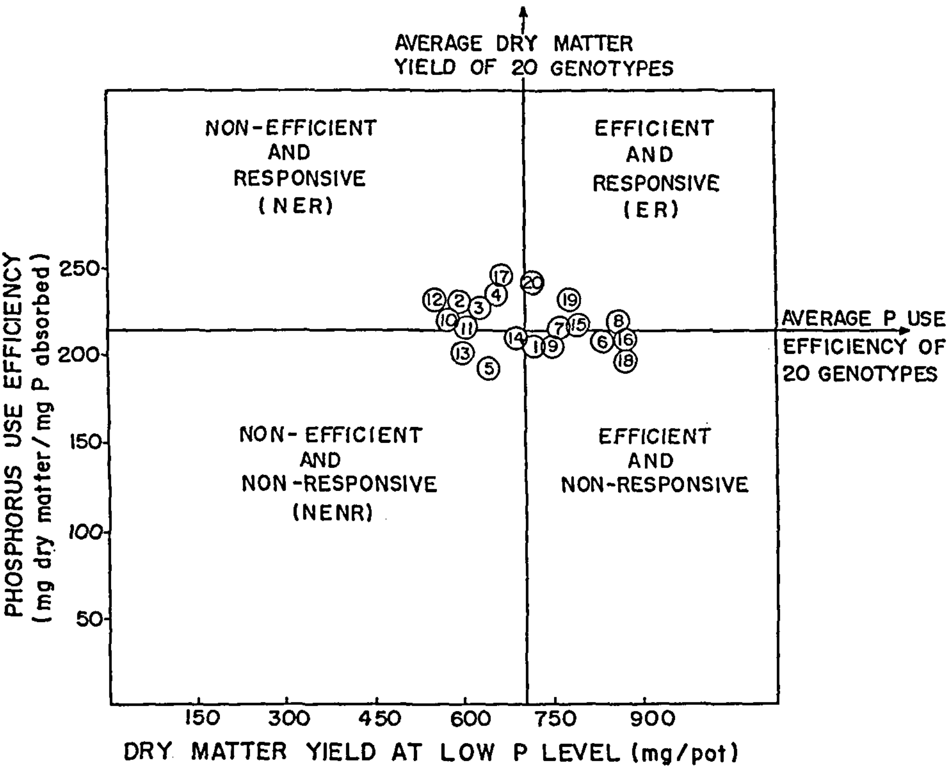

FIGURE 1. Classification of 20 upland rice genotypes for phosphorus-use efficiency. Values in circles refer to cultivar numbers which are cited in Table 6.

Plant height varied from 30 to 48 cm at the low P level, 54 to 77 cm at the medium P level, and 65 to 79 cm at the high P level. Similarly, shoot-root ratio varied from 0.80 to 1.17 at the low P level, 2.47 to 4.00 at the medium P level, and 3.21 to 4.53 at the high P level. This means that the shoot-root ratio varied more at the medium P level as compared to the low and high P levels. This may be associated with a significant increase in dry weight of shoot with a increase of the P level up to the medium P level (Table 2).

Phosphorus concentration in shoot was significantly higher among genotypes only across the three P levels (Table 4). It did not change significantly among genotypes at the low and high P levels (data not shown). At the low P level, the P concentration varied from 0.5 to 0.6 $g \cdot kg^{-1}$ and this level is considered below the critical level for four-week-old rice plants. Adequate P levels for 34-day-old rice plants is reported to be about 2.5 $g \cdot kg^{-1}$ in an Oxisol of Central Brazil (Fageria, 1994). This means that concentration changes in plant tissue only occur at adequate P levels. At too low and too high P concentrations, this did not change much. At a lower P level, there is deficiency, and at a higher P level, there is saturation.

Root length across P levels among genotypes varied from 36 to 46 cm, root dry weight varied from 0.48 to 0.68 $g \cdot pot^{-1}$, and shoot dry weight varied from 1.52 to 2.22 $g \cdot pot^{-1}$ (Table 5). Significant differences among genotypes indicate a difference in P utilization at a given level of P supply.

Phosphorus concentration in the root did not differ significantly among genotypes, but P uptake in the root and shoot differed significantly ($P<0.01$) among genotypes (Table 6). A significant difference in P uptake in the roots as well as shoots among genotypes may be related to a difference in dry matter production. In the shoot, this may also be due to higher P concentration.

Phosphorus use efficiency, defined as mg dry weight (root and shoot) produced per unit of P absorbed, varied significantly among genotypes (Table 6). Results of P-use efficiency were plotted against dry matter production of roots and shoots under the P-stress (low P) level, as has been suggested by Fageria and Baligar (1993).

The average yield of 20 genotypes at a low P level and average P-use efficiency indices were used to separate genotypes into four groups (Figure 1): i) efficient and responsive (ER)—genotypes which produced more than average dry matter yield and higher than average P-use efficiency (genotypes Guarani, Rio Paranaiba, CNA 7681, CNA 7864, and CNA 7451); ii) efficient and nonresponsive (ENR)—genotypes which produced more than average dry matter yield, but P-use efficiency was less than average (genotypes CNA 6187, CNA 7890, CNA 7680, CNA 7875, and CNA 7690); iii) non-efficient and responsive (NER)—genotypes which produced less than average dry matter yield, but P-use efficiency was higher than average (genotypes CNA 6710, CNA 7127, CNA 7119, IAC 1335, IAC 1343, IAC 1205, and CNA 7706); and iv) non-efficient and nonresponsive (NENR)—genotypes which produced less than average dry matter yield as well as less than average P-use efficiency (genotypes CNA 7645, CNA 6724-1, and CNA 7911).

From a practical point of view, the genotypes which produced well under the low level of P and responded well to added P are the most desirable. These results indicate that upland rice genotypes differ in P-use efficiency. Both inter- and intraspecific variation in P nutrition have been recognized among cereal species and genotypes (Fageria et al., 1988), differences in P use which habe been shown to be genetically controlled (Fageria and Baligar, 1993).

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